

**AN INVESTIGATION OF WINTER WEATHER  
TYPES OF THE WESTERN NORTH ATLANTIC  
OCEAN AND THEIR RELATION TO THE  
NORTH AMERICAN ZONAL INDEX**

**George L. Raring  
Earl P. Finney, Jr.  
and  
John Corry**











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An Investigation of Winter Weather Types  
of the Western North Atlantic Ocean and their Relation to  
The North American Zonal Index

by

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Department Committee on  
Graduate Students

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in the Department of the Interior  
of the United States and the  
Department of the Interior

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Department of the Interior  
Bureau of Land Management  
Washington, D. C. 20240  
Dear Sir:

2

Reference is made to your letter of the 10th day of  
January, 1964, in which you requested that the  
Department of the Interior

be advised

of the results

of the

investigation conducted by the

1964

Department of the Interior

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\_\_\_\_\_

Very truly yours,

Director of the Bureau of Land Management

\_\_\_\_\_

Enclosed for the Bureau of Land Management  
is a copy of the report of the  
investigation conducted by the

\_\_\_\_\_



#### ACKNOWLEDGMENT

The authors wish to express their thanks to Dr. Sverre Pettersen and Mr. Jerome Ranas of M.I.T., Dr. C.G. Rossby of the Weather Bureau and Comdr. J.B. Anderson, U.S. Navy for their invaluable suggestions in the preparation of this paper. They also wish to express their thanks to Mr. R.A. Allen of the five day forecast project for his assistance in the preparation of the statistical analysis for this paper.



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C	General type B
D	General type C
E	General type D
F	General type E
G	General type F
H	General type G
I	General type H
J	General type I
K	General type J
L	General type K
M	General type L
N	General type M
O	General type N
P	General type O
Q	General type P
R	General type Q
S	General type R
T	General type S
U	General type T
V	General type U
W	General type V
X	General type W
Y	General type X
Z	General type Y

## I. INTRODUCTION

The purpose of this paper is (1) to extend the investigations made in a previous paper by Lieutenant Lackner and Lieutenant Stone in which an attempt was made to forecast the weather conditions over the North Atlantic from synoptic reports received from the North American continent only, and (2) to make further contributions of forecasting methods based on the methods outlined in their paper.

The work of Lackner and Stone was confined to winter months for the reason that it is only during this period that pressure systems are consistently strongly defined and consequent air flows definite. Likewise, the winter months are the period of roughest conditions, except for hurricanes, and consequently the period most difficult for forecasting. The area concerned was along the Atlantic Coast, from Newfoundland to Florida and six hundred miles to seaward. By recognizing recurring weather patterns over this area and the eastern part of North America, they were able to classify them into six weather types. Then, dividing the area into five-degree squares, they made tables showing the percentage of cloudiness, average winds and average weather for each square when a given type exists. Of the maps examined, 56% were classified under the types; the remaining 44% were unclassifiable.

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The work of Lashley and others was confined to winter months for the reason that it is very difficult to obtain accurate data on the behavior of the animals during the winter months. The work of Lashley and others was confined to winter months for the reason that it is very difficult to obtain accurate data on the behavior of the animals during the winter months.



The principle objective in this paper will be that of finding a means of forecasting the occurrence of the weather types. Dr. Rossby and collaborators have shown that there is a definite relationship between the zonal index and the general circulation pattern. If it can be shown statistically that there is some correlation between a zonal index available from the North American continent and weather types, then there is a means to extend the usefulness of the methods outlined by Lackner and Stone.

## II. THE GENERAL CIRCULATION

A thorough understanding of the thermodynamic and dynamic processes of the atmosphere is necessary in order to understand and predict weather processes. This is especially important when an attempt is made to extend a forecast over long periods of time or into areas from which one receives no reports. Improvements can be made only as more is learned of the general circulation of the earth's atmosphere and of its causes.

In conjunction with the development of the five-day forecasting project at M. I. T., Rossby and his collaborators have made marked progress in theorizing the causes of the General Circulation. A general knowledge of this work is necessary for an understanding of the significance of the Zonal Index.

The principal objective of this paper will be that of  
 finding a means of forecasting the occurrence of the weather  
 types. Dr. Schaefer and his colleagues have shown that there is  
 a definite relationship between the mean index and the geo-  
 metrical characteristics of the weather. It is not an exact relationship  
 that there is some correlation between a mean index available  
 from the newly designed instrument and weather types, but  
 there is a means of determining the relationship of the various con-  
 ditions by means of the index.

## II. THE GENERAL THEORY

A thorough understanding of the thermodynamic and dynamic  
 processes of the atmosphere is necessary in order to under-  
 stand and predict weather phenomena. This is especially im-  
 portant when an attempt is made to forecast a future state  
 of the atmosphere at time or place where the weather is  
 variable. In forecasting one must not only be familiar with  
 the general circulation of the atmosphere but also of the  
 details.

In connection with the development of the five-day fore-  
 casting period at U. S. Navy and the collaboration days  
 have been proposed in forecasting the means of the general  
 circulation. A general knowledge of the state is necessary  
 for an understanding of the significance of the mean index.



A brief summary of the theory follows:

For a perfectly smooth, homogeneous, non-rotating earth receiving heat from the sun with a maximum at the equator decreasing to a minimum at the poles, a simple meridional circulation would result. This would cause the heated equatorial air to rise and the relatively cool polar air to sink, resulting in a pressure gradient toward the poles at upper levels and toward the equator at the surface. The resulting path of air particles in this circulation would then be: rising at the equator, northward flow at upper levels, sinking at the poles and southward flow along the surface to the equator.

When the earth is set in rotation about its axis and surface friction brought into play, the above described circulation would break down as shown in Plate I. First, the deflecting force due to the earth's rotation would cause horizontal flowing particles to be deflected toward the right (in the northern hemisphere) resulting in a westerly component aloft and an easterly component at the surface (Figure A). The westerly wind aloft would be brought down at the poles and the easterly surface winds would be projected up at the equator because of the inertia effect of the earth's rotation (Figure B). The pressure distribution must adapt itself to this motion. This will cause a sea level pressure maximum between the westerly and easterly surface components in Figure





B. Under the influence of the pressure built up to the south, surface winds near the poles will be frictionally retarded, which will cause this stream to turn northward again (Figure C). As the air at the pole continues to cool and sink, this returning air must be forced aloft, thereby establishing the cellular circulation shown in Figure D.

Let us now consider the energy which maintains each cell. The equatorial and polar cells have cyclonic or counter-clockwise circulation (looking eastward) and may be called direct cells as they carry heat from warm to cold source, thereby transforming the potential energy of heat difference into the kinetic energy of the air particles. The central cell with anticyclonic or clockwise circulation (looking eastward) receives its energy from the viscous drag of the two direct cells. In other words, the strong westerly winds of the adjacent direct cells create eddies with approximately vertical axes. Through the action of these eddies, the momentum of the westerlies is transferred throughout the central cell. The excess of centrifugal force acting on the west winds of middle latitudes, forces the air southward, but equilibrium is never reached, since the air still further to the south, instead of piling up and thus permitting the establishment of an adequate cross-current pressure drop, cools through radiation and sinks to lower levels where it acquires a northward movement.





The pressure difference observed at the surface is a reflection of the velocities of the frictionally driven westerlies in this central cell. Consequently, it follows that the pressure difference between the limits of the westerlies must give a good indication of the relative strength of the westerlies.

A profile of the mean meridional pressure distribution around the earth can be obtained by summing the pressure values around a latitude circle from sea level pressure maps. This was done for daily, monthly, and annual pressure means, and it was found that the minimum and the maximum in the mean profiles lay at nearly  $55^{\circ}$  North and  $35^{\circ}$  North respectively. The difference between the means of the pressures about the  $35^{\circ}$  North and  $55^{\circ}$  North latitude circles was taken as an indication of the strength of the westerlies, and it has been called the Zonal Index.

From the theorem of the conservation of absolute vorticity, Rossby has shown that the westerly winds have stable characteristics. That is, when they are disturbed by thermal or frictional changes upon crossing continental coast lines, they maintain their general easterly flow but with sinusoidal paths. These patterns show up on high level pressure charts.

It has been shown that the following relation holds:

The pressure difference observed at the surface is a result of the variation of the velocity of the water surface. It follows that the pressure difference between the surface and the bottom of the water gives a good indication of the relative strength of the water.

A profile of the sea surface is obtained by means of a sounding line and is obtained by means of the sounding line. This was done for daily, hourly, and annual pressure soundings. It was found that the surface and the bottom of the sea are parallel to each other at nearly 90° North and 90° South respectively. The difference between the surface and the bottom of the sea is 30° North and 90° South latitude circles was found to be 10° North and 90° South latitude circles, and it was found that the sea surface is parallel to the bottom of the sea.

From the results of the observations of the surface of the sea, it is found that the surface of the sea is not a smooth surface, but is a rough surface. This is, when the sea is disturbed by the wind or by the surface of the sea. The surface of the sea is not a smooth surface, but is a rough surface. This is, when the sea is disturbed by the wind or by the surface of the sea. The surface of the sea is not a smooth surface, but is a rough surface. This is, when the sea is disturbed by the wind or by the surface of the sea.



$$C = U \left( 1 - \frac{L^2}{L_s^2} \right)$$

Where:  $C$  = eastward velocity of the perturbation (trough or wedge).

$U$  = velocity of the zonal westerly wind.

$L$  = wave length of the perturbation.

$L_s$  = wave length of the perturbation for which  $C$  is zero (standing wave length).

$$L_s = 2\pi \sqrt{\frac{UR}{2\Omega \cos \phi}} \text{ where } R = \text{Radius of the earth.}$$

$\Omega$  = angular velocity of the earth, and  $\phi$  = the latitude.

It also has been shown that the number ( $N$ ) of such perturbations is:

$$N = \sqrt{\frac{2\Omega R \cos^3 \phi}{U - C}}$$

Since these theoretical considerations show that the number of perturbations in middle latitudes and the rate of their movement are functions of the intensity of the westerly winds, it follows that there must be a close relationship between weather patterns with their surface pressure changes and distribution and the Zonal Index which, as mentioned above, is a measure of the intensity of the westerlies.

### III. THE ZONAL INDEX

As described above, the Zonal Index is the average pressure about the 55° North latitude circle subtracted from the

$$C = U \left( 1 - \frac{L^2}{L^2} \right)$$

$$\frac{U}{\sqrt{1 - \frac{L^2}{L^2}}} = \dots$$

$$\frac{U}{\sqrt{1 - \frac{L^2}{L^2}}} = \dots$$

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average pressure about the  $35^{\circ}$  North latitude circle. In computing the index, the isobars are first drawn from all available reports. The pressure value for each ten degrees of longitude is then picked off from the map and tabulated and summed for the  $35^{\circ}$  latitude circle. This procedure is then repeated for the  $55^{\circ}$  latitude circle. The sum from the  $55^{\circ}$  latitude circle is then subtracted from the sum from the  $35^{\circ}$  latitude circle and the difference divided by the number of pressure readings used along the latitude circles.

If desired, the Zonal Index may be subdivided into partial indices which will show the index just between certain specified longitudes. In this paper, two partial indices were used, one between  $60^{\circ}$  West and  $120^{\circ}$  West longitude, called the "Continental Index" and the other between  $60^{\circ}$  West and  $180^{\circ}$  West longitude, called the "Continental-Pacific Index". The Continental Index can be accurately established from reports from the United States and Canada. The Continental-Pacific Index, however, has to depend on reports available from the Pacific which may not be forthcoming during wartime. A reasonably accurate index can be computed, however, by means of observations from Pearl Harbor, Midway, Dutch Harbor, Kanaga, and Sitka in conjunction with the continental reports.

As the Continental-Pacific Index is more extensive, it is assumed that it is the best index to indicate weather types.

average pressure about the 35° North latitude circle. In some  
cases the index, the latitude and time zones are all avail-  
able together. The pressure value for each was derived of the

circle in the field of view the map and indicated and  
summed for the 35° latitude circle. This pressure is then  
reported for the 35° latitude circle. The map from the 35°  
latitude circle is then compared from the map from the 35°  
latitude circle and the difference divided by the number of  
pressure readings used along the latitude circle.

It should be noted, the small index may be substituted into the  
final latitude circle with some error that between circles  
specified longitude. In this case, the small index was  
used, one between 60° and 120° west longitude, called the  
"smaller index" and the other between 120° and 180°  
west longitude, called the "smaller index". The  
development index can be naturally considered from the  
from the small index and small. The small index is  
index, however, has to depend on the small index from the  
small index and not be determined from the small. A small  
smaller index can be compared, however, by using of  
coordinates from each index, which index, which  
and then in comparison with the development index.

As the small index is not determined, it is  
assumed that it is the small index of the small index.



As this has a high correlation factor with the Continental Index (.820), either may be used with practically equivalent results.

From computation of daily values of the indices, it was noted that the trend of the values was quite regular, but the day-to-day variation was so great that a more or less saw-toothed curve resulted. It was therefore decided to use five-day mean values, a procedure followed by the long-range forecasting group at M. I. T. All index values used in this paper are of the five-day running mean type; that is, the average of the value for the present day and the four preceding days. This practice tends to minimize the influence on the index of individual migrating pressure centers and thereby gives more weight to the intensity, position, and changes of the quasi-permanent centers.

#### IV. THE WEATHER TYPES

Lackner and Stone arrived at weather type-classification by examining surface maps for October 1938 through March 1939 plus the Deutsche Seewarte synoptic maps for the polar year 1932-33. In general, they grouped the maps into good and bad weather patterns for the area along the East Coast extending from 600 miles eastward of Florida to Newfoundland. The types determined in their work are reproduced in Plates II to IV.

As this has a high correlation factor with the predicted in-  
dex (0.82), which may be used as a guide in estimating the  
index.

From observation of daily values of the index, it was  
found that the trend of the index was quite regular, but the  
day-to-day variation was so great that a more or less con-  
tinuous curve resulted. It was therefore decided to use five-  
day mean values, a procedure followed by the International  
Council of the I. T. All these values were in this paper  
used of the five-day running mean that is, the average of  
the values for the previous day and the four preceding days.  
This procedure seems to eliminate the influence on the index of  
individual migrating persons and daily river flow  
which is the intensity, position, and change of the front-  
ier.

#### IV. THE INDEX

Index and index of weather type-division  
by examining weather maps for the years 1930-1939 and 1940-1949  
plus the weather maps for the years 1950-1959 and 1960-1969.  
In general, the index was found to be quite good and was  
used for the years 1930-1969. The index was found to be  
from 0.50 index values at 1930 to 1969. The index  
decreased in 1930 and was 0.50 in 1969.



Below are given the criteria for each type as defined by them.

(1) Bad Weather Types:

Type A<sub>1</sub>

Referring to the photostat containing type A<sub>1</sub>, the following three centers of action are noted: (1) a low on the northeastern coast, moving gradually toward Newfoundland; (2) a high pressure cell starting to build up over Georgia and the Carolinas and proceeding in the wake of the above low; (3) a high pressure area entering the United States from Canada over the Great Lakes region and moving to the southeast.

Type A<sub>2</sub>

Centers of action: (1) a filling cyclone well up in Newfoundland region with the Atlantic polar front paralleling the coast and quasi-stationary; (2) a series of waves developing and travelling along the front; (3) an elongated high with NE-SW axis and extending from Canada over the Great Lakes into the southern states; (4) the Bermuda High well established to the east of the front.

Type A<sub>3</sub>

Centers of action: (1) an intense low at sea paralleling the coast; (2) a high pressure area entering the United States from the middle of Canada building up to the rear of the low and moving rapidly toward the coast.

Below are given the sketches for each type as defined by them.  
(1) Flat against type:

#### Type A1

Notwithstanding the character of the sketch, the following three variants of each type are given: (1) a low on the horizontal axis, moving gradually toward the horizontal; (2) a high pressure well reaching to half up over the horizontal and the horizontal axis, moving in the same of the above type; (3) a high pressure axis reaching the vertical axis from the left over the horizontal axis and moving to the horizontal.

#### Type A2

Character of system: (1) a filling of the well up in the horizontal region with the vertical axis from the left; (2) a series of waves filling the space and gradually increasing; (3) a series of waves developing and traveling along the horizontal axis; (4) a series of waves with the axis and extending from the horizontal axis to the horizontal axis; (5) the horizontal axis well as indicated to the right of the horizontal axis.

#### Type A3

Character of system: (1) a series of waves traveling along the horizontal axis; (2) a high pressure axis reaching the horizontal axis from the left of the horizontal axis; (3) a series of waves traveling along the horizontal axis; (4) a series of waves traveling along the horizontal axis; (5) a series of waves traveling along the horizontal axis.



### Type B

This type consists essentially of: (1) an elongated high pressure area with a NE-SW axis and extending from Texas to Newfoundland; (2) an intense low off the coast proceeding northeastwards but having its path blocked by the northern portion of the high pressure mentioned in (1); (3) a weak cyclonic activity between the high over the eastern states and the high pressure area over the Rocky Mountain states.

### Type C

Centers of action consist of: (1) a well-developed low pressure in the Nova Scotia area; (2) a high pressure area entering the United States over the Great Lakes region and travelling southeast; (3) a high pressure area over Alabama, Georgia, and the Carolinas and moving eastward; (4) a well marked front between the two highs with wave developments proceeding along it toward the low in the northeast.

## (2) Good Weather Types:

### Type D

This type consists of: (1) an old low pressure center in the Nova Scotia-Newfoundland area; (2) a high pressure cell with N-S axis extending from the Great Lakes to the Gulf states and moving steadily eastward; (3) a weak high pressure system over the West Coast; (4) a low pressure development on the northwest side of the high mentioned in (2) and





with a front from the low separating the two high pressure areas.

Lackner and Stone did not include a table giving dates of occurrence of types, so the authors had to spend considerable time in examining charts to obtain such a table. This is shown in Table "A" and includes the results of examinations of the Deutsche Seewarte charts for the polar year 1932-33, the charts from January 1 to March 13, 1939 (charts for November and December 1938 being available), and the charts from November 20, 1940 to February 23, 1941. The authors identified 141 types out of 250 cases giving a percentage of 56.4%. This percentage is exactly that found by Lackner and Stone. However, identical results are misleading, for, a comparison of the tables of frequencies and persistencies as found by the authors (Table "C") with those listed by Lackner and Stone (Table "D") show that a large latitude must be allowed for the personal factor involved in the identification of a given pressure distribution with the more or less rigid patterns defined in the types.

A variation of type "C" is suggested by the authors which retains on the whole the same characteristics as defined by Lackner and Stone. This would occur as a transition from type C when the high over Alabama, Georgia, and the

with a front from the low surrounding the two high pyramids

above.

Lachner and Stone did not include a table giving dates of occurrence of types, as the authors had no good material. This is in some cases as early as 1861. This is shown in Table "I" and includes the results of examination of the British Museum charts for the years 1861-72, the charts from January 1 to March 31, 1873 (charts for November and December 1872 being available), and the charts from November 30, 1873 to February 27, 1881. The charts identified all types out of 120 charts giving a percentage of 35.4. This percentage is exactly that found by Lachner and Stone. However, identical results are obtained, too, a comparison of the series of types and percentages as found by the authors (Table "I") with those listed by Lachner and Stone (Table "II") show that a large latitude may be allowed for the personal factor involved in the identification of a given specimen characteristic with the more or less rigid pattern defined in the types.

A variation of type "B" is suggested by the authors

which exists in the whole and was designated as B-

found by Lachner and Stone. This would seem to be identical

with type C when the high over Alameda, Nevada, and the



Carolinas has merged with the Bermuda high, and Tg and Tm air flow into the southeastern United States below the polar front.

An additional good weather type was discovered which had a frequency of occurrence that warranted its being classed among the weather types. It is given the designation Type E and is reproduced on Plate V.

The essential features of Type E are: (1) a low trough extending from the western Gulf northeastward to the eastern Great Lakes ending in an occlusion in the vicinity of Hudson Bay; (2) an extensive Bermuda high extending over southeastern United States; (3) a quasi-stationary front extending from W to E in the vicinity of Bermuda separating the Bermuda high from the re-enforcing transitional Pc air; (4) a polar continental high over the central and northwestern United States.

The percentages of cloudiness, winds, and weather are given in Table "E". It is apparent that Type E is generally a good weather type. The relatively high percentages of rain and fog in sectors 6 and 9 are due to wave motion on the quasi-stationary front in the vicinity of the Virginia Capes.

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... among the ...  
... and is ...

The essential features of Type 1 are: (1) a low ...  
extending from the ...  
... is ...  
Type 2: (2) an ...  
United States; (3) a ...  
to 2 in the vicinity of ...  
from the ...  
essential ...

The ... of ...  
given in Table ...  
... type. The ...  
and ...  
... in the vicinity of the ...



## V. ANALYSIS OF STATISTICAL DATA

The basis for using a partial index in this paper is the successful correlation of the partial index with the total index by members of the five-day forecasting staff at M.I.T. With this in mind, it is assumed that an index for the area chosen is indicative of the circulation in the relatively small area of the west Atlantic under consideration.

From an examination of the Continental and Continental-Pacific curves for three winters, Plates VI, VII, and VIII, it will be apparent that there is a good correlation. This might be expected, as the former area comprises 7/13 of the latter. This expected correlation was computed from the formula,  $r^n = \frac{\sqrt{\sum C^2}}{\sqrt{\sum T^2}}$ , where  $\sum$  indicates summations, C the values of the Continental Index, and T the values of the Continental-Pacific Index. The coefficient was found to be .685 for the three winters investigated. The actual correlation was computed from the usual formula for the correlation factor:

$$r = \frac{\sum(TC) - \frac{(\sum T)(\sum C)}{N}}{\sqrt{\left(\sum T^2 - \frac{(\sum T)^2}{N}\right)\left(\sum C^2 - \frac{(\sum C)^2}{N}\right)}}$$

where N indicates the total number of values used and other symbols as above. The resulting coefficient was found to be

The main purpose of this paper is to present a method of determining the relative importance of the various factors which enter into the determination of the total index of prices of the various commodities. It is assumed that the index of prices of the various commodities is a function of the various factors which enter into the determination of the total index of prices of the various commodities.

It is assumed that the index of prices of the various commodities is a function of the various factors which enter into the determination of the total index of prices of the various commodities. It is assumed that the index of prices of the various commodities is a function of the various factors which enter into the determination of the total index of prices of the various commodities. It is assumed that the index of prices of the various commodities is a function of the various factors which enter into the determination of the total index of prices of the various commodities.

$$I = \sqrt{\frac{(\sum I_i)^2 - \sum I_i^2}{n}} \quad (1)$$

where  $I$  is the index of prices of the various commodities,  $I_i$  is the index of prices of the various commodities, and  $n$  is the number of commodities.



.820 which is a relatively high factor in statistical experience.

From the above results one is able to determine the Continental-Pacific Index from the Continental Index, or to determine one index by means of the other, by use of this factor .820.

An interesting feature of the curves is the variation in periodicity and amplitude from year to year. The curve for 1932-33 shows that the periods were long and the amplitudes large, giving three maxima for the season. During the winter of 1938-39 the periods were short and the amplitude small with one exception. For 1940-41 the periods were moderate and the amplitudes moderate. Thus, if it is to be found that weather types occur in conjunction with specific values of zonal index or with trends of the zonal index, then the frequency of occurrence of types will vary from year to year.

As was stated in the introduction, the aim of this investigation was to find a means of forecasting the occurrence of a weather pattern or type by means of the zonal index. This might be done (1) if a certain zonal index value occurred concurrently with a certain weather type; (2) if a definite trend of the zonal index toward lower or toward higher values is associated with a certain weather type; (3) if the trend of the





zonal index indicates a transition from one weather type to another; and (4) if the variation of the five-day mean value from the yearly mean value can be identified with a certain weather type.

Plate XI is a graphic representation of the occurrence of values of zonal index for each weather type. As in each plate using block diagrams, the abscissae are values of zonal index in millibars and ordinates frequency of occurrence. By means of the method of first moments, it is possible to arrive at an approximate value of the median, but due to the values in which there were no occurrences, the use of a mean value of zonal index found by this means would be of questionable worth in forecasting of weather types. Scarcity of occurrence of types  $A_2$  and D and the wide scattering in type E preclude the possibility of arriving at a representative mean value. The shape of the diagram for type  $A_3$  suggests two medians, one at about -3 millibars and one at about + 7 millibars.

In a manner somewhat analogous to the analysis of a barograph trace the curves of zonal indices were analyzed with respect to the occurrence of weather types in an attempt to discover some connection between trends of the zonal index and the weather types. The results are shown in Table "B". Again in the cases of types  $A_2$  and D, there are insufficient

usual index indicates a transition from one weather type to another; and (4) it is variation of the five-day mean value from the mean value and is identified with a certain weather type.

Figure 11 is a graph representing the distribution of the weather types at each index for each weather type. As in each place using these figures, the classes are given of each index in millions and indicate frequency of occurrence. The mean of the index at each weather type is indicated by an arrow at the bottom of the graph, but due to the values in which there was no occurrence, the use of a mean value at each index found by this method would be of considerable worth in forecasting of weather types. Accuracy of occurrence of types A and B and the index indicated by the graph is the possibility of existing at a representative mean value. The shape of the diagram for type A, however, was not, as at about -2 millions and one of about + 7 millions.

In a similar manner, the weather types in the analysis of a large group of the weather types at each index were analyzed with reference to the occurrence of weather types in an attempt to discover some possible general trends of the mean index and the weather types. The results are given in Table 12, which is the same as Table 11, but with the weather types



occurrences to arrive at any conclusions, while in the case of types  $A_2$  and C, which have the greatest frequencies, there are roughly twice as many occurrences under definite falling as under definite rising tendencies. Were these the only tendencies to be dealt with, a forecast might be made with fair success; but the scattering of tendencies as shown in Table "B" render forecasting more or less a matter of guesswork when forecasting on tendencies only.

A study of Table "A" in connection with the curves of zonal indices affords no thumb rule as to forecasting transition from one weather type to another by means of the trend of zonal index. On the whole, the type occurrence is spasmodic, except in the case of type  $A_2$  which appears often as a transition from type C. However, the trend is not indicative, as in some cases it was rising from C towards  $A_2$  and in other cases falling.

The results of the investigation of the fourth possibility of connecting zonal index with weather type occurrence are shown in Plates IX and X. The former is a plot of frequency of occurrence of departure from the yearly mean of zonal index for each type. The latter is a similar plot using the departures from the mean of the three seasons investigated. The two diagrams differ slightly because of the low mean index of

...to arrive at any conclusion, while in the case of  
...the ... have the ...  
...as ...  
...the only ...  
...to be ...  
...the ...  
...the ...  
...the ...

A study of ... in connection with the ...  
...the ...  
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...the ...  
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The results of the investigation of the ...  
...the ...  
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...the ...



5.7 millibars for the year 1940-41 as compared to 10.0 and 12.0 millibars for 1932-33 and 1938-39 respectively, but for the analysis they may be considered similar. As in the case of the plotted values of zonal index, again by the method of moments approximate medians may be computed. In the block diagrams for types A<sub>3</sub> and C, this process gives values which are even less reliable than those obtained from the diagrams plotted for actual zonal index because of the more erratic distribution of frequency. For the other types, lack of data and wide scattering allow no definite conclusions to be drawn.

## VI. SUMMARY AND CONCLUSIONS

The statistical analysis has shown that the correlation is poor between the Continental or Continental-Pacific Zonal Index and the weather types in the western North Atlantic. Such a finding is not consistent with the results obtained in the five-day forecast project at M.I.T. The discrepancy may be explained by the fact that five-day mean pressure charts are used by the five-day forecasters, whereas in this paper an attempt was made to correlate the zonal index with daily pressure maps. The minor perturbations caused by topography over the eastern portion of North America are not smoothed out as is accomplished by a five-day mean pressure map. Also, the area covered by the type patterns is relatively so small that





the circulation is only a small part of that represented by the zonal index and in this particular area is broken up by the minor perturbations as they move off the continent.

The rough means of zonal index and rough means of departure from the mean zonal index found for each type occurrence, though not to be considered reliable for purposes of forecasting, still show that there is a connection between zonal index and pressure distribution. Further research covering many winters and with a rigid adherence to the criteria of the pressure types should result in reliable values of zonal index as an indication of type occurrence. However, such indications will be useless when a pressure distribution varies slightly from the rigid criteria. The authors found it impossible to hold to rigid criteria in scanning the maps because of the scarcity of occurrence of types under these conditions. It is believed that in the block diagrams of this paper, the number of type maps which loosely fit the criteria outweigh those which fit the criteria more exactly and thus the correlation of a definite type is hidden.

The authors were unable to obtain the percentages of occurrence and the persistencies found by Lackner and Stone. It is evident that the personal factor involved in type identification renders forecasting by this method a matter of personal opinion.

The information is sent in a plain text format to the  
the school and is also available to the public.  
The school is not responsible for the security of the information.

relation of a definite time is indicated.

The company will make it possible to obtain the necessary information from the company's records and the company's records.

TABLE "A" TYPE CLASSIFICATION

1932-33			1939			1940-41		
Dec.	1	B	Jan.	1	C	Nov.	20	C
	2	B		2	C		21	E
	3	C		3	C		22	C
	4	E		4	A3		23	C
	5	C		5	E		24	C
	6	C		6	D		25	A3
	7	E		8	C		26	E
	12	E		9	E		27	A3
	14	A1		10	A3		28	A3
	15	C		11	A3		30	C
	17	B		12	A3	Dec.	1	A3
	18	B		16	A3		5	C
	23	E		17	A3		6	A3
	25	E		21	A1		7	E
	26	C		22	A3		9	A1
	28	C		23	D		10	C
Jan.	1	B		25	A3		13	C
	5	C		27	C		16	E
	6	C		28	C		18	D
	7	C		29	C	Jan.	5	A3
	8	C		31	A3		11	A3
	10	C	Feb.	1	A3		13	A3
	11	C		2	E		18	A2
	12	A3		4	A3		20	A1
	13	A3		7	A3		21	D
	16	C		9	C		23	C
	17	C		10	E		24	C
	18	C		12	A1		25	C
	19	E		13	C		26	A3
	20	C		15	A3		29	D
	21	C		16	D	Feb.	3	A2
	22	E		18	C		9	A2
	25	E		19	C		10	B
	28	A3		20	B		12	B
	29	A3		21	A2		13	E
	30	A3		22	A3		15	A3
Feb.	1	E		23	A1		16	A1
	6	A1		24	C		18	A3
	7	E		25	A2		19	A3
	9	A1		26	A3		20	A3
	15	C		27	A3		21	A3
	16	C	Mar.	1	A1		22	A3
	19	B		2	B		23	A3
	20	E		3	B			
	22	D		5	C			
	23	E		6	A3			
	25	E		7	A3			
	26	A3		8	A3			
	27	A3		10	A3			





TABLE B

Classification Vs. Tendencies

TYPE TENDENCY	A <sub>1</sub>	A <sub>2</sub>	A <sub>3</sub>	B	C	D	E
/	6	1	2	5	2	3	2
/	1		2				
^		2	1	1	2		2
^			2		2		
^	1		20	2	21	2	5
^		1	3		4		3
^			1	1	1	1	1
^			1	1			
^		1	2	1	2		2





TABLE "C"

Table of Frequencies and Persistences as found by Authors

---

A <sub>1</sub>	4% occurrence 1 day duration 100%	B.	4% occurrence 1 day duration 45% 2 days duration 55%
A <sub>2</sub>	2% occurrence 1 day duration 100%	C.	17% occurrence 1 day duration 33% 2 days duration 43% 3 days duration 35% 4 days duration 9%
A <sub>3</sub>	17% occurrence 1 day duration 45% 2 days duration 32% 3 days duration 24% 6 days duration 15%	D.	3% occurrence 1 day duration 100%
		E.	9% occurrence 1 day duration 100%

---

TABLE 7

Table of Properties and Dimensions of Steel in Bridge

A1	12 in. diameter 1 1/2 in. diameter 1 1/2 in. diameter	12 in. diameter 1 1/2 in. diameter 1 1/2 in. diameter
A2	12 in. diameter 1 1/2 in. diameter 1 1/2 in. diameter	12 in. diameter 1 1/2 in. diameter 1 1/2 in. diameter
A3	12 in. diameter 1 1/2 in. diameter 1 1/2 in. diameter 1 1/2 in. diameter 1 1/2 in. diameter	12 in. diameter 1 1/2 in. diameter 1 1/2 in. diameter 1 1/2 in. diameter 1 1/2 in. diameter
A4	12 in. diameter 1 1/2 in. diameter 1 1/2 in. diameter	12 in. diameter 1 1/2 in. diameter 1 1/2 in. diameter

TABLE "D"

Table of Frequencies and Persistencies as found by Lackner  
and Stone.

---

A <sub>1</sub>	10% occurrence 1 day duration 21% 2 days duration 50% 3 days duration 22% 4 days duration 7%	B.	10% occurrence 1 day duration 0% 2 days duration 37% 3 days duration 27% 4 days duration 27% 5 days duration 9%
A <sub>2</sub>	6% occurrence 2 days duration 40% 3 days duration 60%	C.	9% occurrence 2 days duration 64% 3 days duration 27% 4 days duration 9%
A <sub>3</sub>	9% occurrence 1 day duration 15% 2 days duration 69% 3 days duration 16%	D.	12% occurrence 1 day duration 12% 2 day duration 44% 3 days duration 25% 4 days duration 19%

---



Table of Programmatic and Financial Data for 1964

Continued

Program	Funds Available	Funds Obligated	Funds Expended	Percent Obligated	Percent Expended
A1	100	100	100	100	100
1 day session	100	100	100	100	100
2 day session	0	0	0	0	0
3 day session	0	0	0	0	0
4 day session	0	0	0	0	0
5 day session	0	0	0	0	0
6 day session	0	0	0	0	0
A2	100	100	100	100	100
1 day session	100	100	100	100	100
2 day session	0	0	0	0	0
3 day session	0	0	0	0	0
4 day session	0	0	0	0	0
5 day session	0	0	0	0	0
6 day session	0	0	0	0	0
A3	100	100	100	100	100
1 day session	100	100	100	100	100
2 day session	0	0	0	0	0
3 day session	0	0	0	0	0
4 day session	0	0	0	0	0
5 day session	0	0	0	0	0
6 day session	0	0	0	0	0

T A B L E

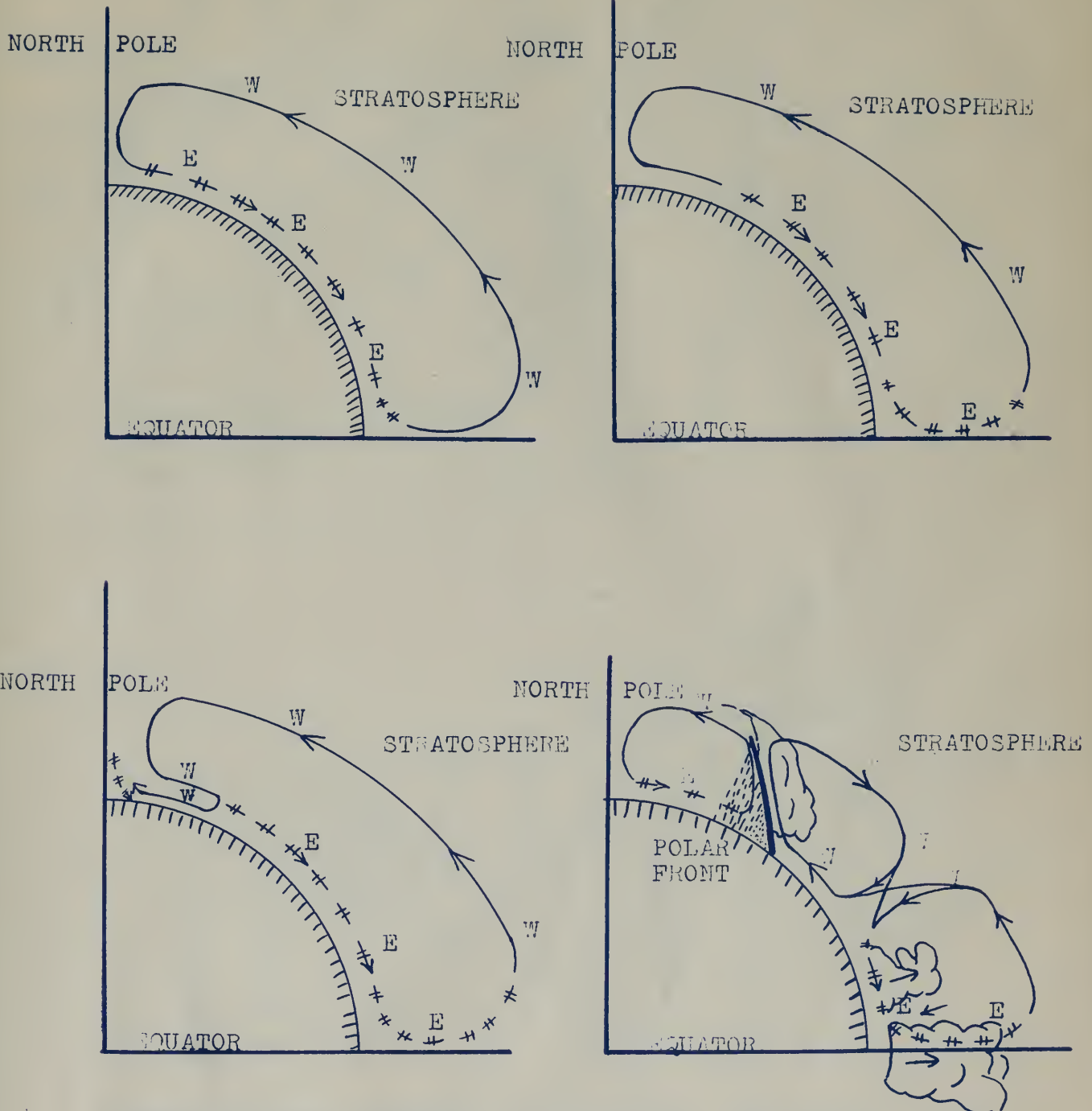
Type B

[illegible]



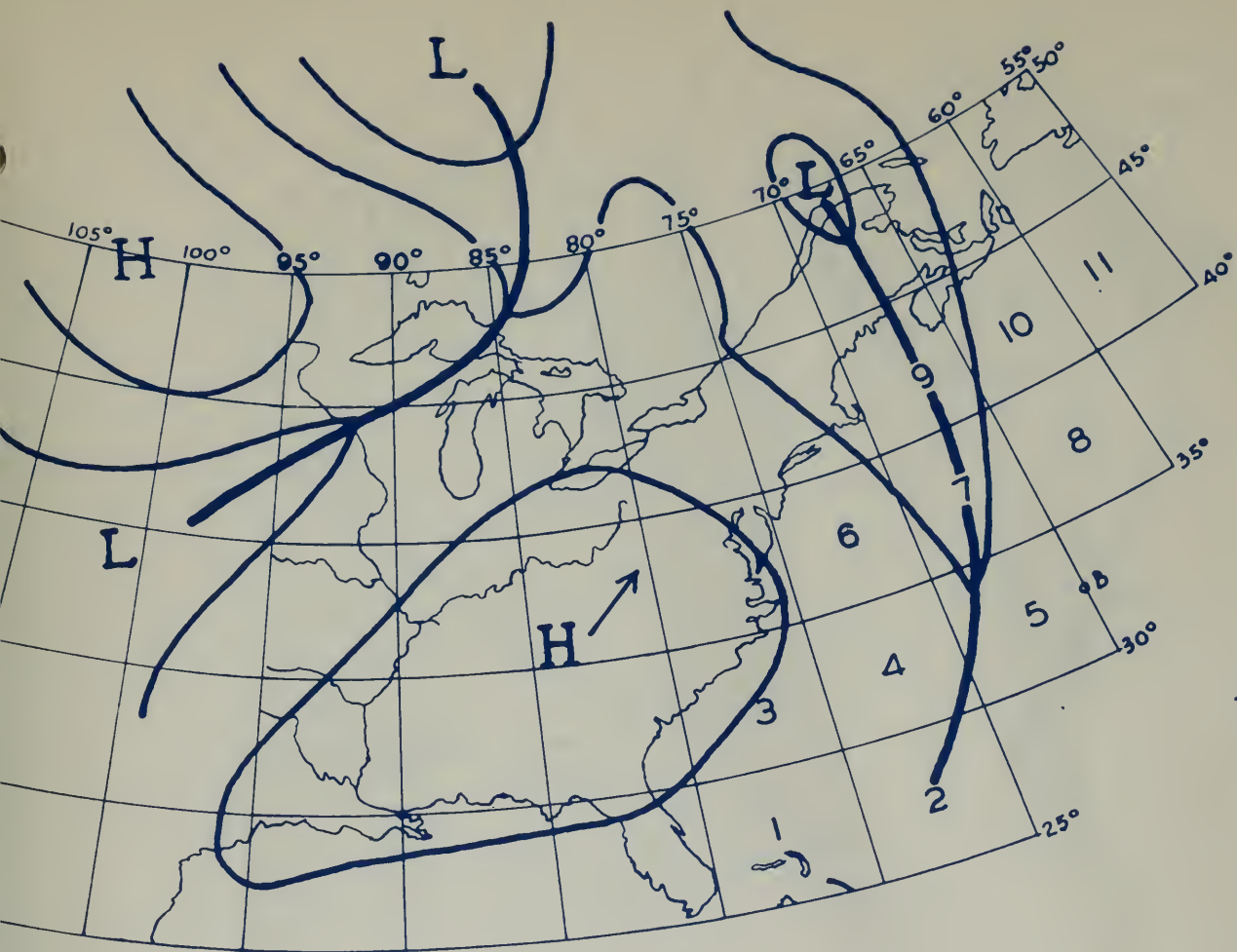


PLATE NO. I

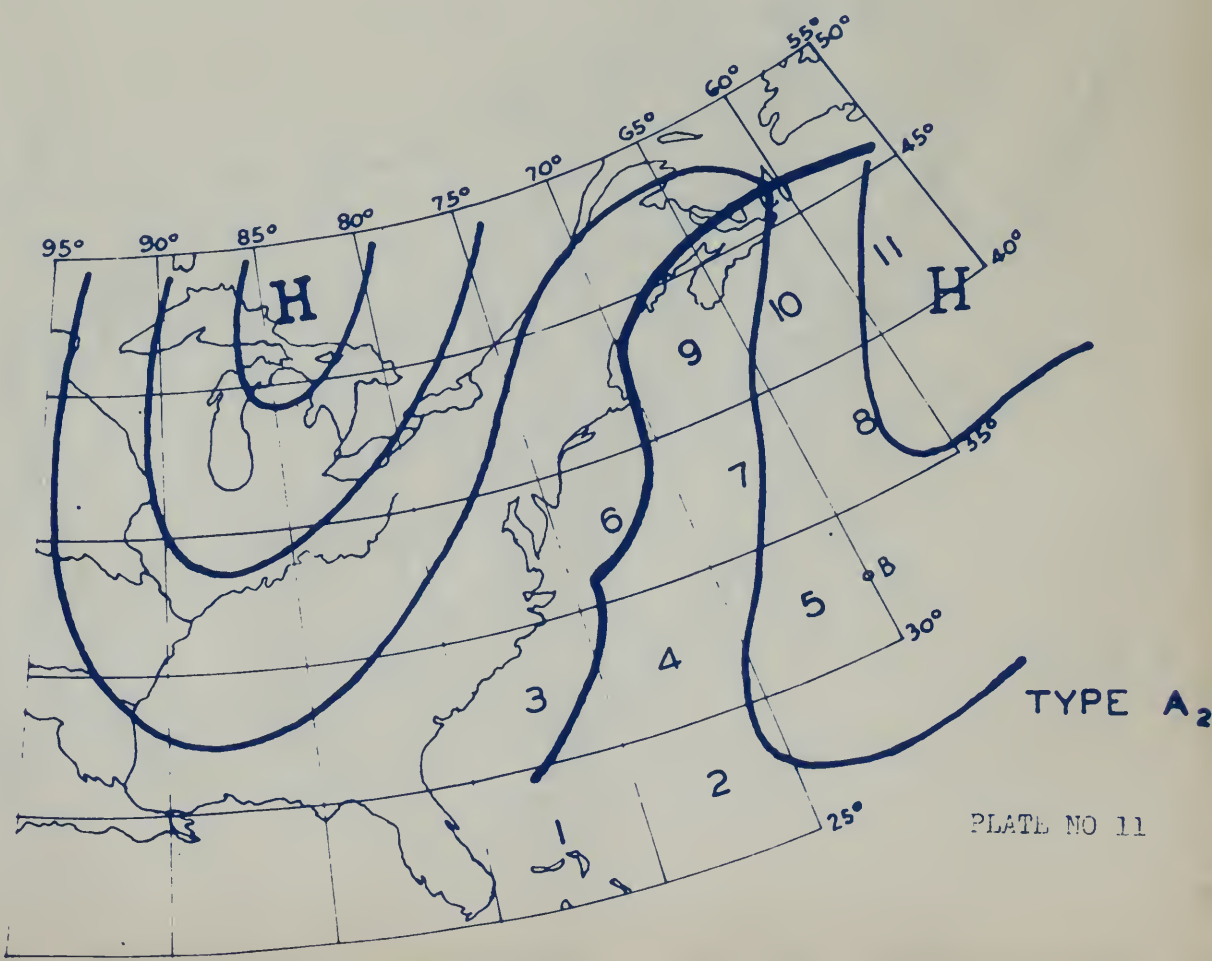


Dynamics of the Breakdown of Meridional Circulation under the Influence of the Earth's Rotation and of Surface Friction.  
(From Notes on the General Circulation of the Atmosphere by C.G. ROSSBY.)





TYPE A<sub>1</sub>



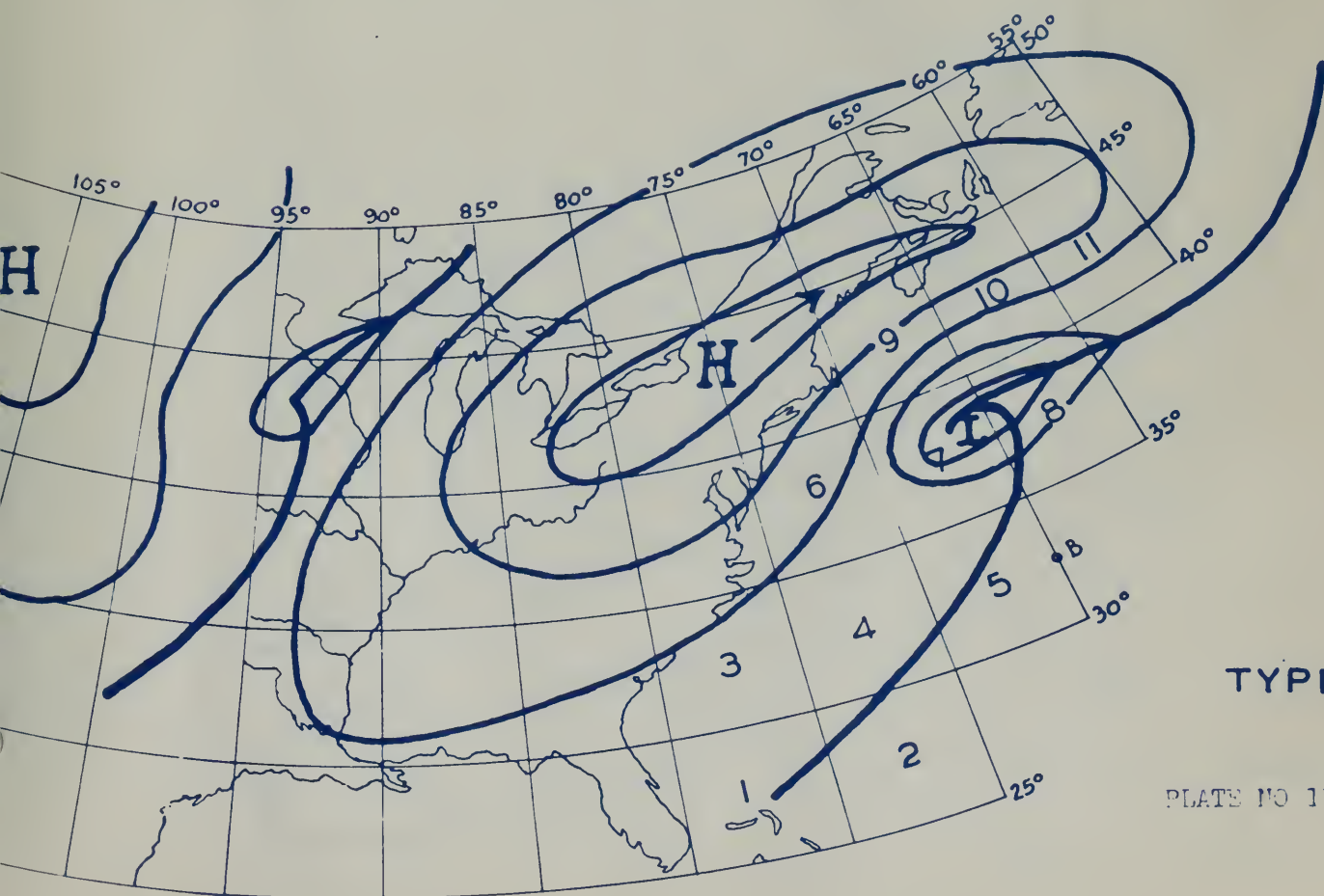
TYPE A<sub>2</sub>







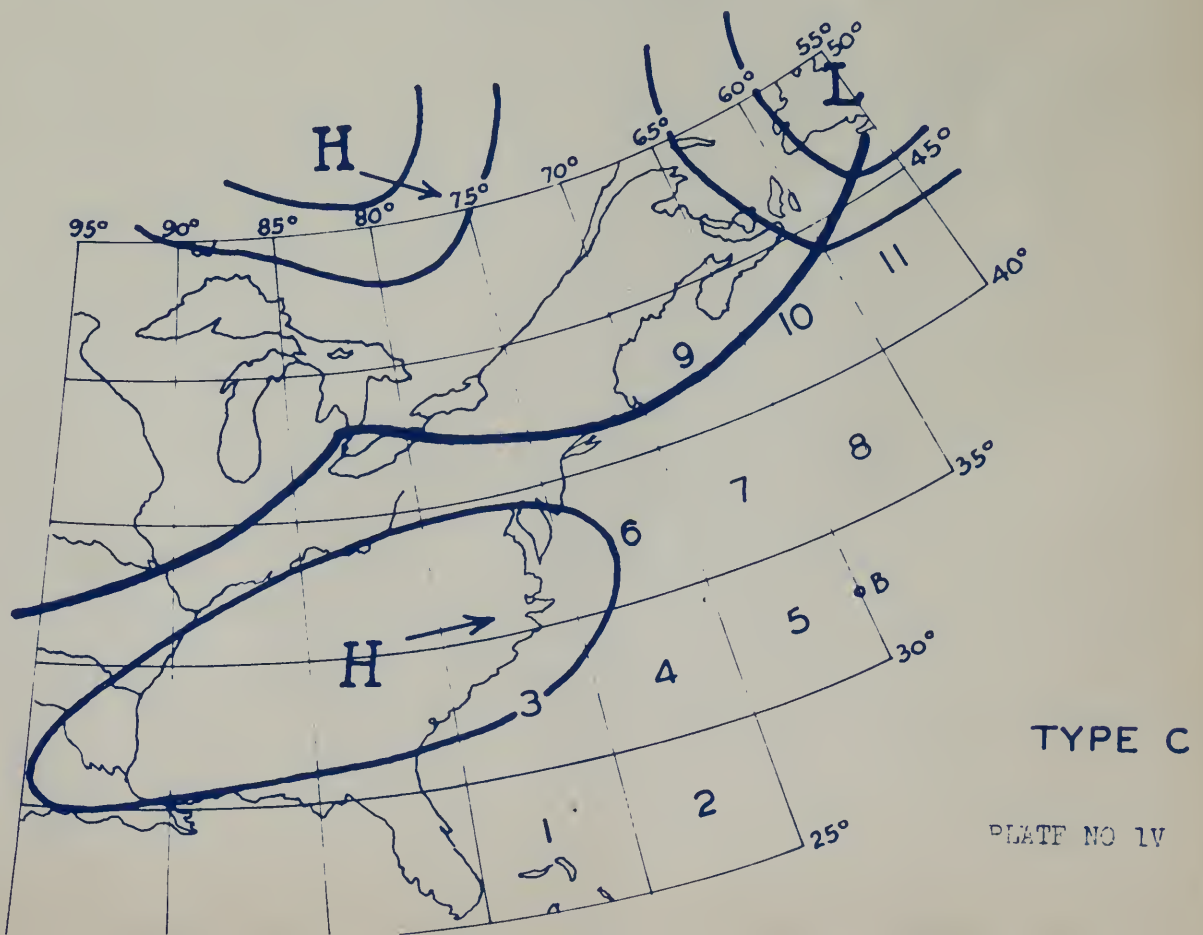
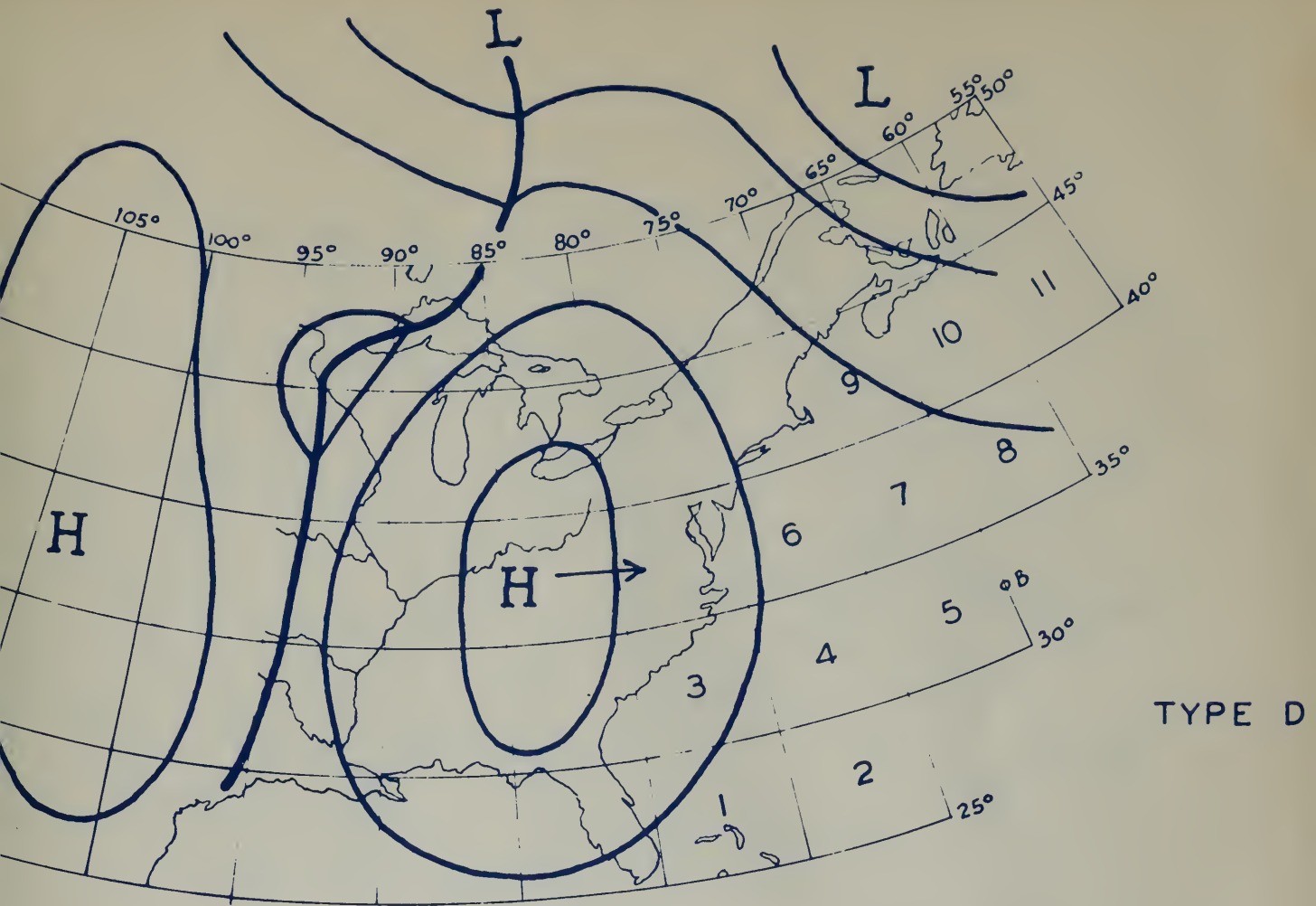
TYPE A<sub>3</sub>



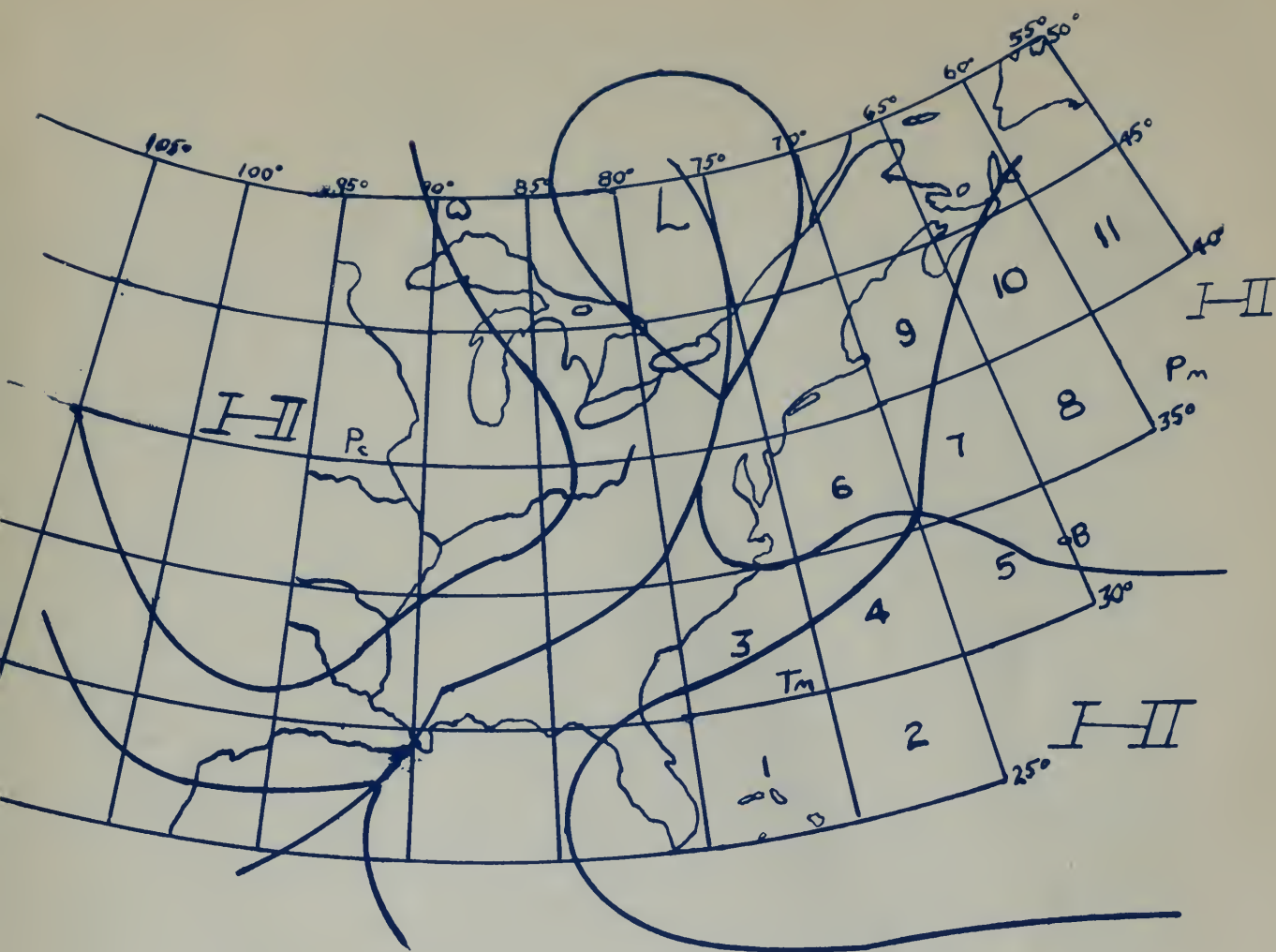
TYPE B









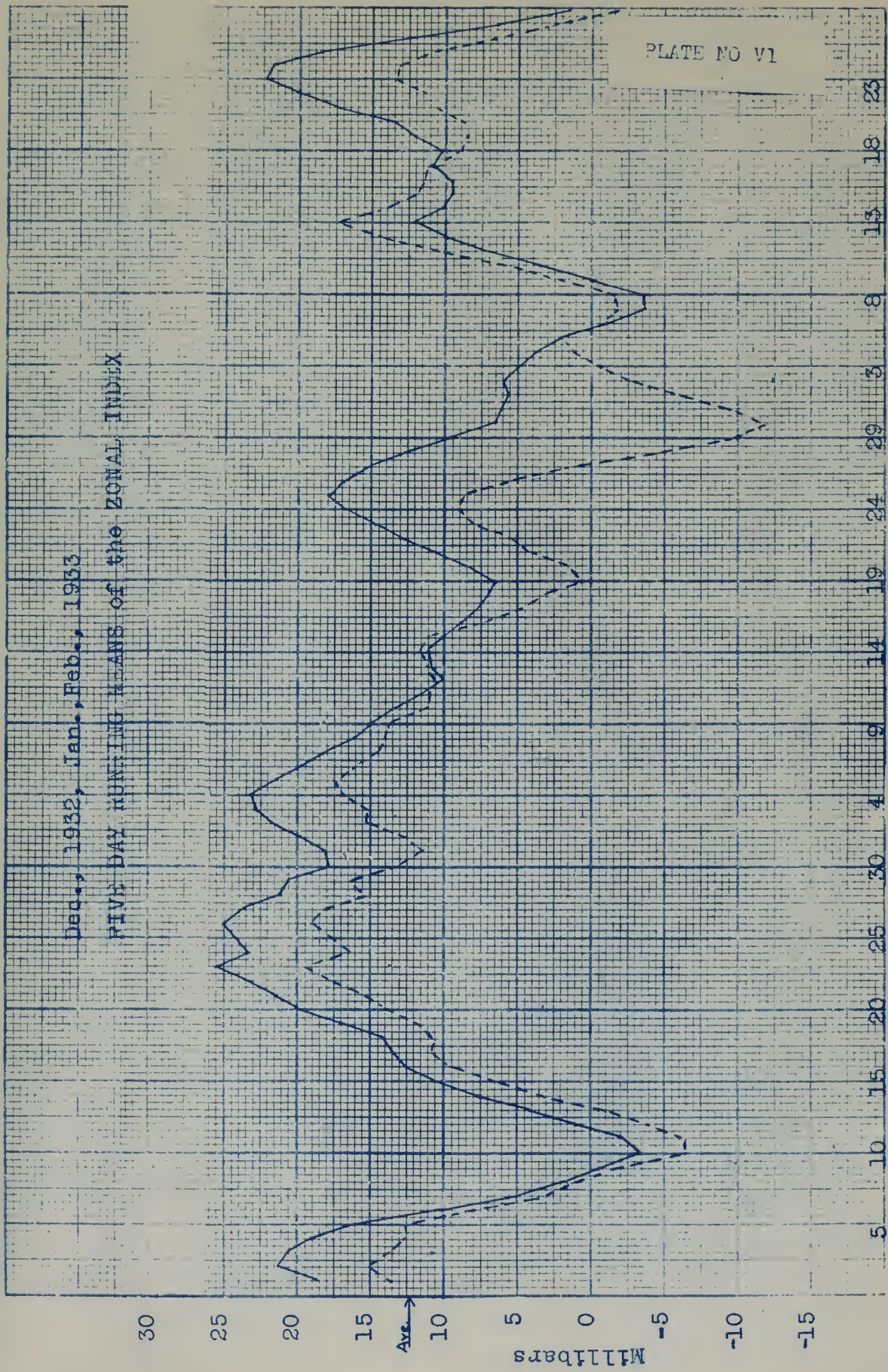


TYPE "E"

PLATE NO V







Dec.

Jan.

Feb

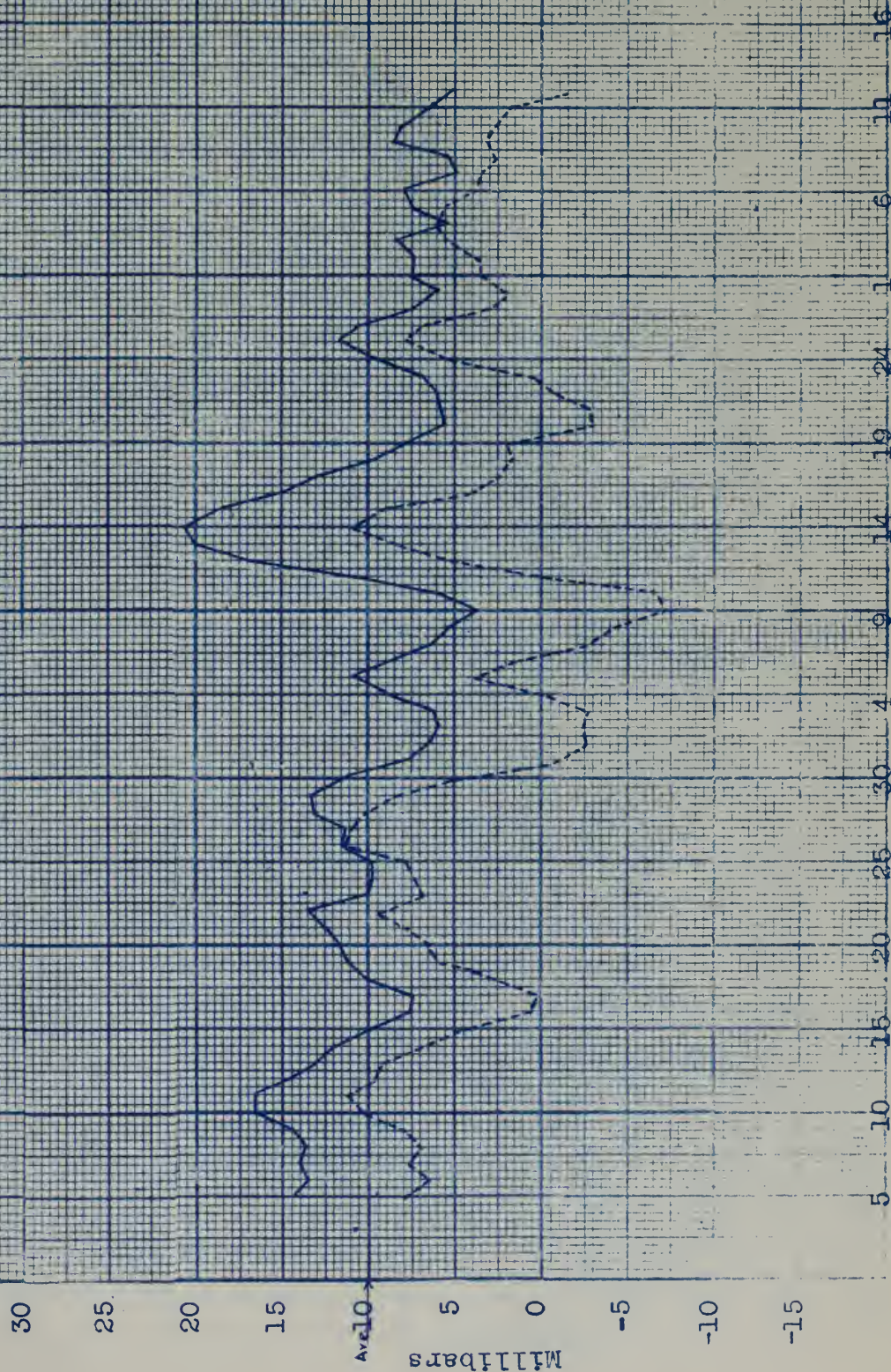
— (60-180 degrees west)

- - - (60-120 degrees west)





JAN., FEB., MAR., 1939  
FIVE DAY RUNNING MEANS OF THE ZONAL INDEX



Mar.

Feb.

Jan.

— (60-180 degrees west)

- - - (60-120 degrees west)



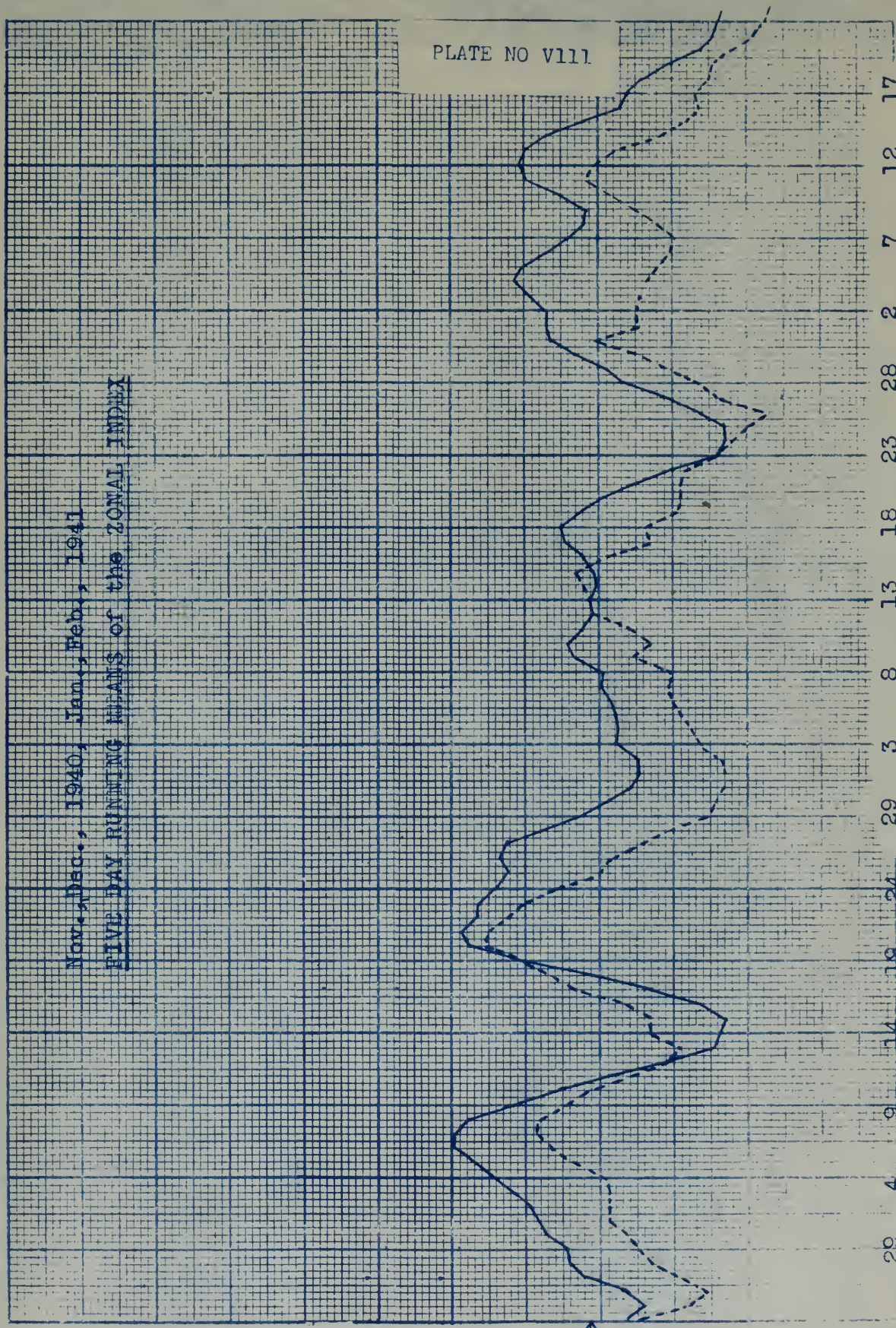


Nov., Dec., 1940, Jan., Feb., 1941  
 FIVE DAY RUNNING MEANS OF THE ZONAL INDEX

Millibars  
 25  
 20  
 15  
 10  
 5  
 0  
 -5  
 -10  
 -15

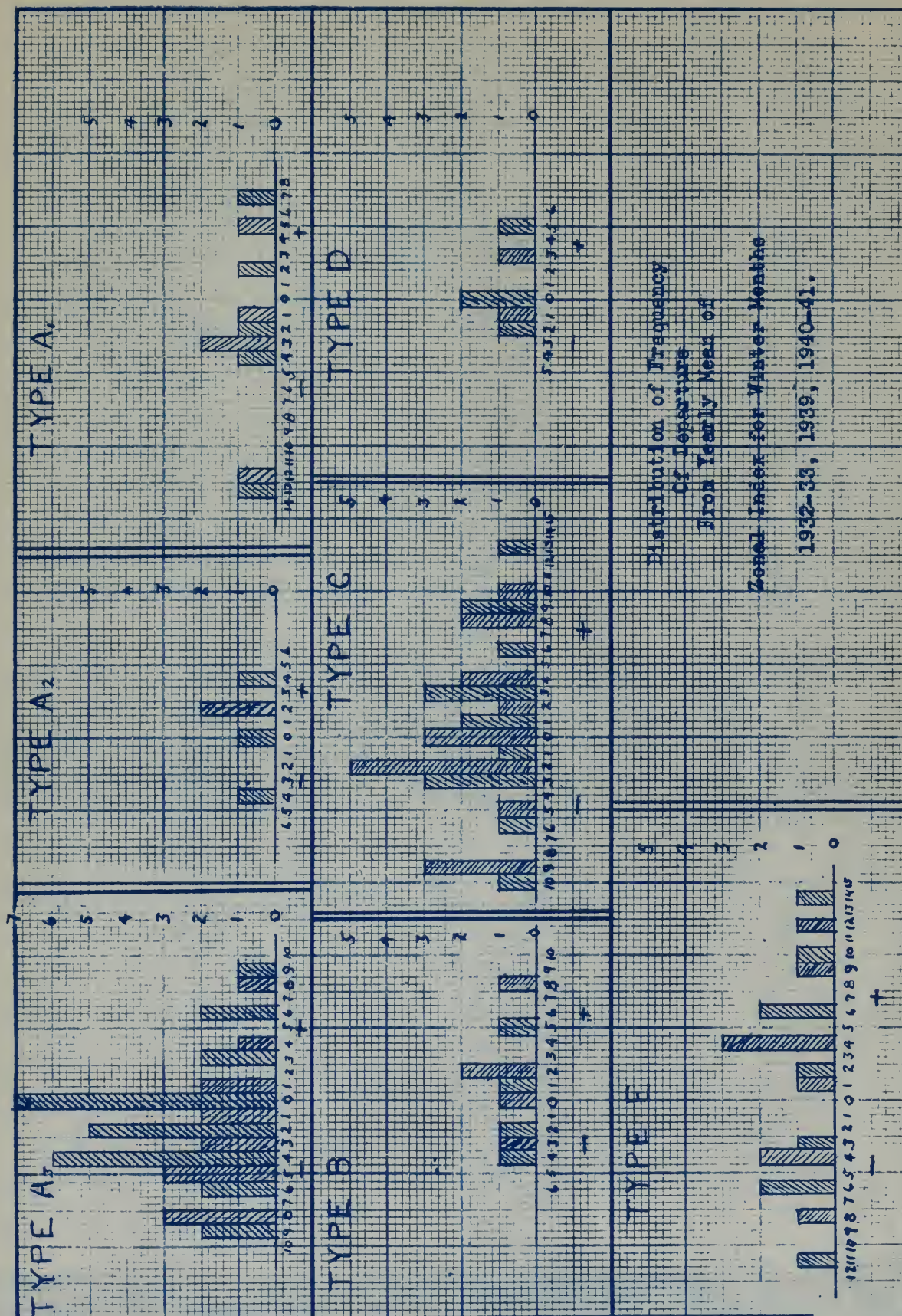
Nov. 29 4 9 14 19 24 29 Dec. 1 4 7 10 13 16 19 22 25 28 31 Jan. 3 6 9 12 15 18 21 24 27 30 Feb. 2 5 8 11 14 17

Dec.  
 — (60-180 degrees west)  
 - - - - (60-120 degrees west)



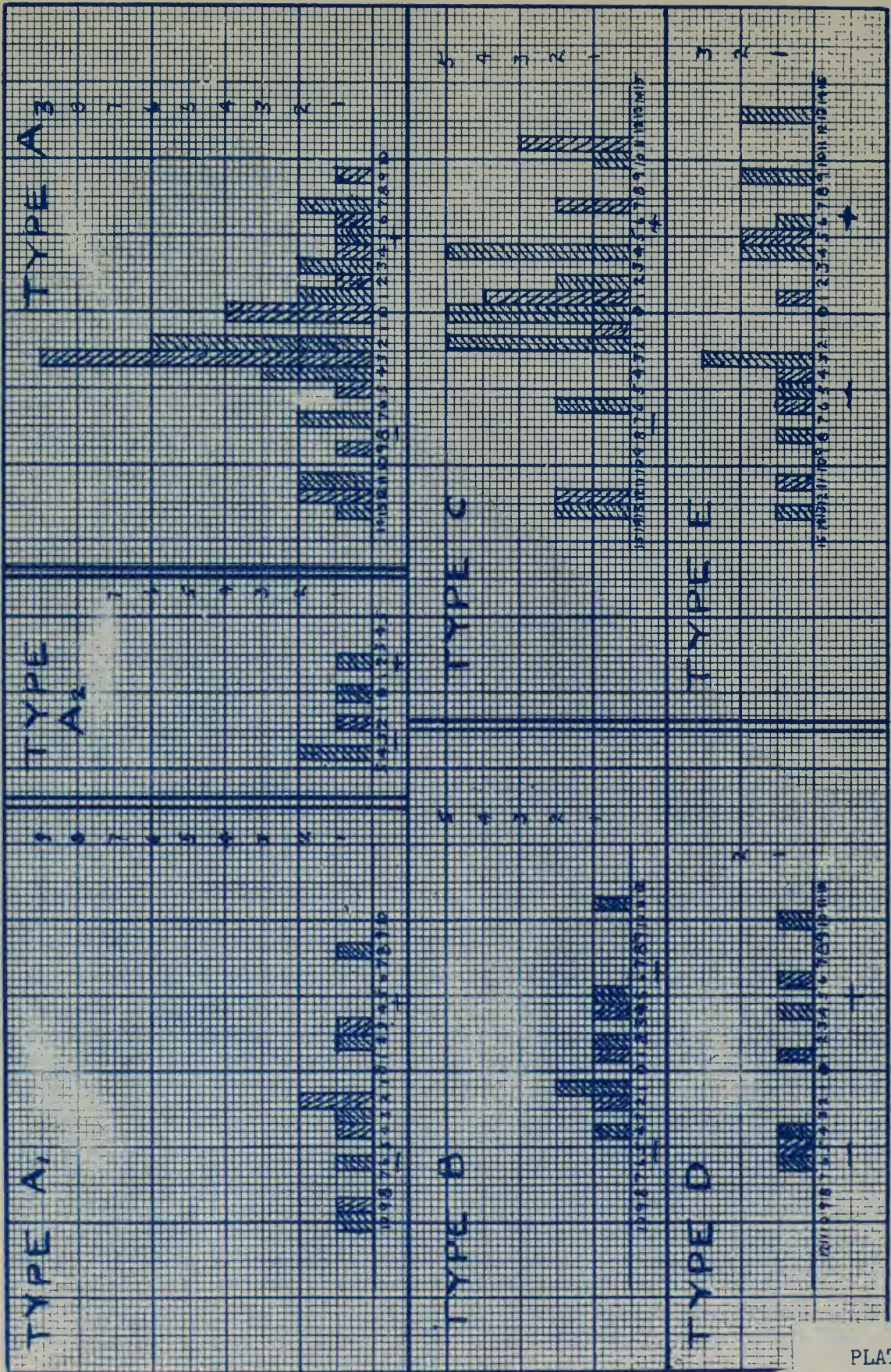








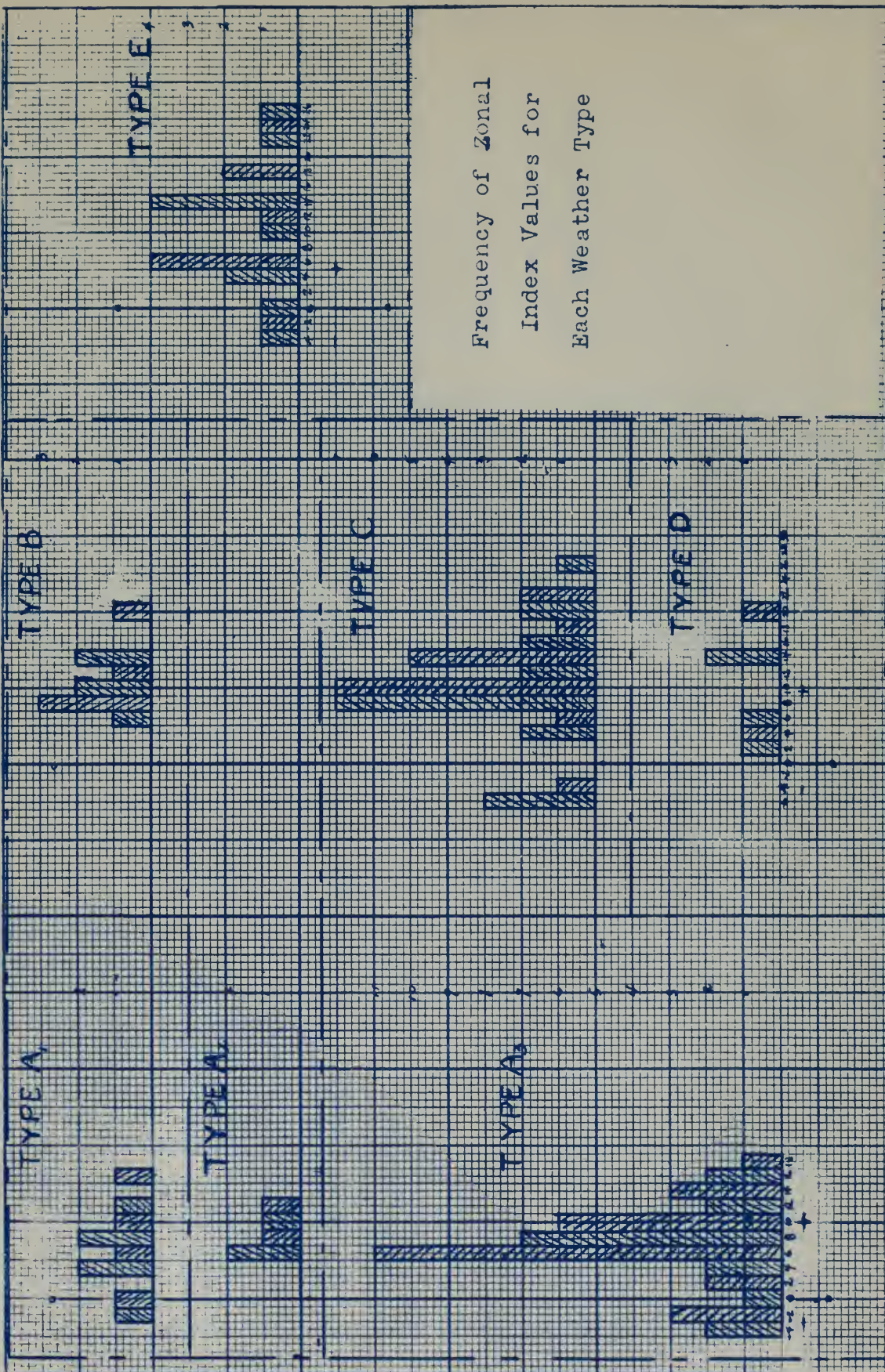




Distribution of Frequency of Departure  
from Three-year Mean of Zonal Index for  
Winter Months 1932-33, 1939, 1940-41







Frequency of Zonal  
Index Values for  
Each Weather Type















JA 17 58  
JA 17 58  
8 SEP 72

BINDERY  
BINDERY  
22060

Thesis

R22 Raring

36434

An investigation of winter  
weather types ...

JA 17 58  
8 SEP 72

BINDERY  
22060

Thesis

R22 Raring

36434

An investigation of winter  
weather types of the western  
North Atlantic Ocean ...



thesR22

An investigation of winter weather types



3 2768 002 05297 9

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